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# **Lessons Learned from NASA's Habitat Analog Assessments**

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**First Community Workshop on  
CAPABILITIES FOR HUMAN HABITATION AND OPERATIONS IN CIS-LUNAR SPACE:  
WHAT'S NECESSARY NOW?  
MOODY GARDENS, GALVESTON, TX  
21 & 22 SEPTEMBER 2011**



# Agenda

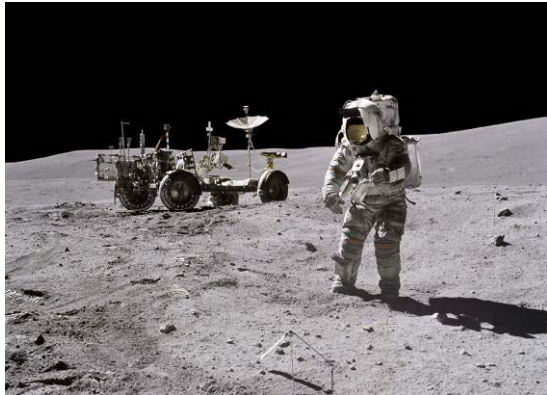
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- ◆ **What is an “analog mission”**
- ◆ **Analog missions in a Capability Driven Framework**
- ◆ **Role of analog missions and tests**
- ◆ **Example 1: Inflatable Habitat Field Demonstration**
- ◆ **Example 2: Habitat Demonstration Unit**
- ◆ **Overall Conclusions**



# What is an “analog mission”?

- ◆ An **analog** is an activity performed in a representative environment that is similar to a feature of the target mission.



## Feature mapping

Physical Environment  
Concept of Operations  
Flight systems and technologies  
Science activities  
Medical/Physiological/Psychological  
Systems of systems interaction



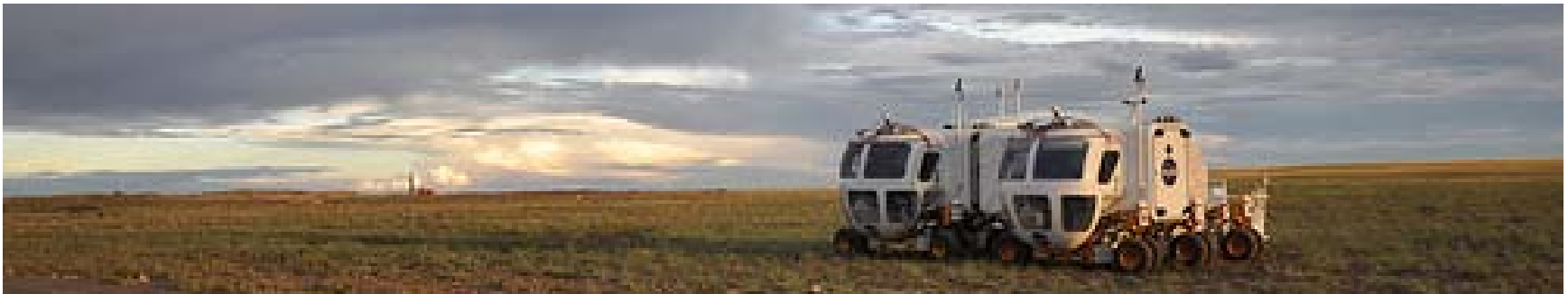
- ◆ An **analog mission** is an activity that maps **multiple** features of the target mission in an **integrated** fashion to gain an understanding of system-level interactions and integrated operations.



# Analog Missions Objectives

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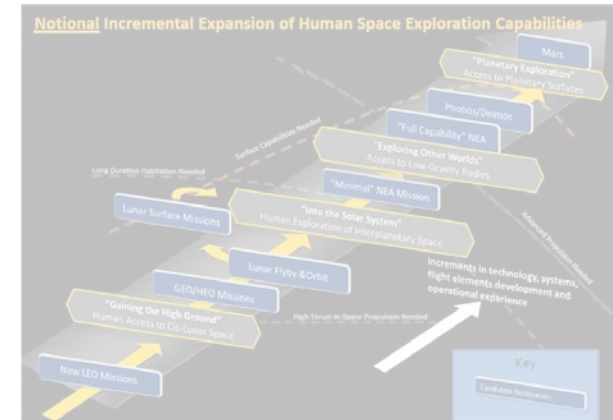
- Learn → Gain a deeper understanding of architectural relevance, system interactions, driving requirements definition, concept of operations, system development and the technology investment strategy.
- Test → Evaluate and validate requirements, concepts of operations, technologies and system interactions.
- Train/Inform → Train crew, ground teams, managers, engineers, and technologists in modes and challenges of exploration.
- Engage → Excite and engage the general public, international partners, and potential teaming institutions in the Exploration Vision through joint human/robotic analog missions and educate the next generation of explorers.





# Analog Missions Support a Capabilities-Driven Framework

- ◆ The current human exploration strategy is structured around a capability-driven approach rather than one based on a specific destination and schedule
  - This framework enables multiple destinations and provides increased flexibility, greater cost effectiveness, and sustainability
- ◆ Evolving capabilities will be based on:
  - Previously demonstrated capabilities and operating experience
    - *Analog missions provide a venue and structure for these demonstrations and help build operating experience*
  - New technologies, systems and flight elements development
    - *Analog missions are one element in the mid- to high-level TRL development stages*
  - Concept of minimizing destination-specific developments
- ◆ Multiple possible destinations/missions would be enabled by each discrete level of capability
- ◆ Would allow reprioritization of destination/mission by policy-makers without wholesale abandonment of then-existing exploration architecture
  - *Analog missions are a flexible and cost-effective means to bring together the systems and organizations to investigate alternative approaches for achieving each discrete capability level*



*Analog Missions are an integral step in achieving capabilities-driven framework*



# Progressive Expansion of Capabilities, Distance, and Duration

## 2. Earth Polar Missions

- Terrestrial Analogs (0) plus :
  - In-situ science operations
  - Surface habitat
  - Surface traverse (mobility and EVA)
  - Surface power
  - Closed-loop life support
  - In-situ resource utilization
  - Supportability & Maintenance
  - International capabilities demonstrations

## 3L. Lunar Missions

- LEO/Near-Earth Space (1) and Earth Polar (2) plus :
  - Landing systems
  - Nuclear power
  - In-situ resource utilization
  - Surface habitat
  - Surface mobility (EVA and rover)
  - Supportability & Maintenance

## 4. Mars Missions

- Lunar (3L) & Deep Space (3D) plus:
  - Mars entry & landing systems
  - Partial-gravity countermeasures

## Transit/Micro-g Systems and Operations

## 3D. Deep Space and Phobos/Deimos

- LEO/Near-Earth Space (1) plus:
  - Crew support for 360 days (habitat)
  - Radiation protection (habitat)
  - Closed-loop life support (habitat)
  - Deep space propulsion (tbd)
  - Cryogenic fluid management
  - Supportability & maintenance

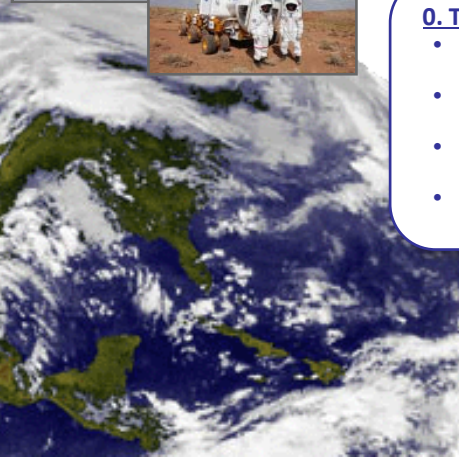
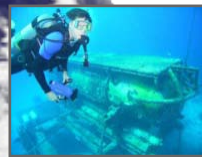
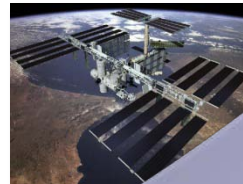
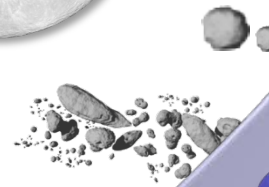
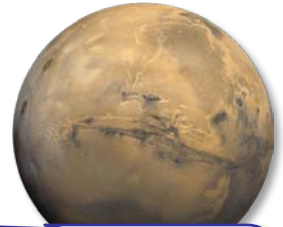
## 1. Low-Earth Orbit and Near-Earth Space

- International Space Station
  - Zero-g research platform
  - Closed-loop life support
- Lunar fly-by, lunar orbit, EM L-Points
  - Heavy lift launch
  - Radiation protection

## 0. Terrestrial Analogs

- Simulated micro-g & hypo-g environments
- Integrated system & operations testing
- Comparative evaluation of alternatives
- International capabilities demonstrations

Surface Systems and Operations







# Role of Analog Missions and Tests

## ◆ Why should we conduct analog missions?

- Reduce risk to crews for human missions on the Moon, Mars and NEOs
- Validate mission designs
- Validate mission operations designs
- Demonstrate integrated use of products from multiple ISECG projects
- Influence engineering and payload system designs via early use in realistic situations
- Help sustain the excitement of exploration for the public well before missions become reality
- ***Learn what works and what doesn't work for exploration missions***

## ◆ How should we plan and execute analog missions?

- Identify architecturally relevant questions with significant uncertainty regarding the implementation of future exploration missions
- Prioritize the importance of obtaining answers to these questions
- Identify the range of viable hardware/operations options or pose hypotheses that could provide part or all of the answer to each question
- Develop analog mission plan, including field test location

### Example: Cold-Trap Sample Return

**Question:** What is the relative productivity of various methods for acquiring, handling, and storing, with minimal heat-induced alteration, samples from “cold traps” located at the lunar poles?

#### **Proposed Analog Mission Components:**

Location: Analogue Terrain Site (e.g. small craters located at Cinder Lakes or larger such as Meteor Crater)

Control Option 1: Earth-based Mission Control (JSC ExPOC)

High-bandwidth Communications with 3 second time-delay

Multiple operators available

Control Option 2: Crewed Habitat-based Mission Control (Local Trailer)

High-bandwidth communications with 0.1 second time-delay

Single operator

Control Option 3: EVA Suit-based Mission Control (EVA Suit)

High-bandwidth communications with no time-delay

Single operator using voice input for commands and HUD for display

Teleoperated rover

Locomotion system capable of descending and ascending representative lunar crater slopes (angle and roughness)

Interface capable of supporting alternative sample acquisition devices

Video and sensor relay and monitoring

Heat management components

Capable of remote driving control

Deployed alternative (to rover) sample acquisition

Constraints on terrain placement (e.g. requires craters of representative size and slopes)

Heat management components

#### **Analog Mission Outcome:**

**Recommendation for extremely cold sample acquisition and handling designs and requirements**

Source	Requirements
HSR&T	Spacecraft-based Command and Control, Communications
ESR&T	Sample handling equipment and procedures
	Wireless Networks for Surface Ops (ASTP/CCED)
	Multimodal Human-Automation Interface (ASTP/STSM/I)
	Surface Transport Rover for cold (40 K) ops (TMP/LPSO)
	Alternative sample collection devices for cold (40 K) ops
Constellation	Surface Habitat Infrastructure Deployment ConOps



Requirement	Option 1	Option 2	Option 3
Sample acquisition			
Sample handling			
Sample storage			
Sample transport			
Sample analysis			
Sample return			

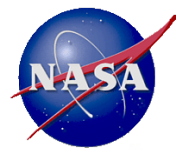


**Example 1:**

**NASA Innovation Partnership Program**

# **INFLATABLE HABITAT FIELD DEMONSTRATION**





# IPP Inflatable Habitat Field Demonstration Overview

## Technical Objective and Team

### Objective:

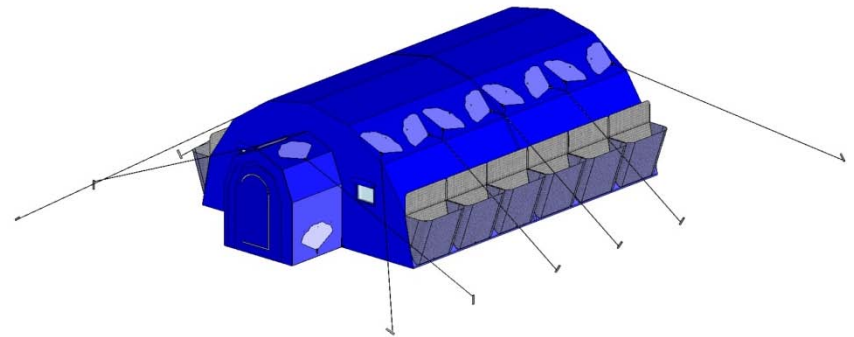
Fabricate an Inflatable Habitat for field testing at the Antarctic. Utilize the Habitat as an analog for understanding the packaging, deployment, integration, durability, and operation of an inflatable habitat in an extreme environment. Demonstrate the instrumentation integration, data capture, download, and thermal model correlation. The field demonstration will provide data to NASA engineers in their support of the ESMD Constellation Program requirements. The inflatable habitat will be evaluated for potential near and long term field deployments.

### Team:

NASA/JSC-PM, requirements definition, SE&I  
NASA/MSFC- requirements definition, thermal modeling  
NASA/LaRC- requirements definition, technical support  
NSF- Requirements definition, logistics, operational support  
ILC Dover- Requirements definition, design, fabrication, demonstration

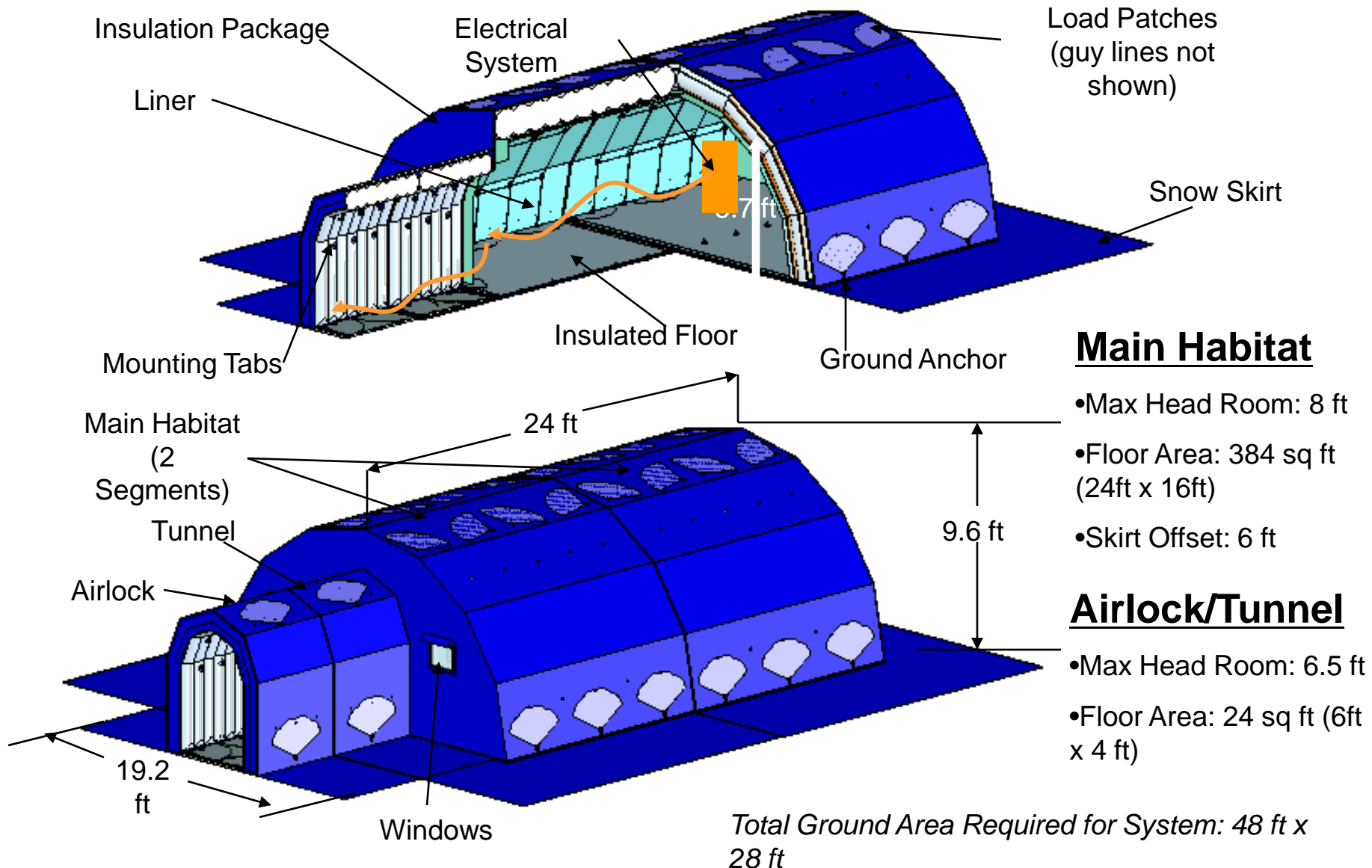
## Technical Milestones

Milestone	Proposed Date	Actual Date	Comments
Complete Req. Matrix	4/12/07		Matrix complete Pending approval
PDR	4/26/07	4/26/07	
CDR	6/26/07		On schedule
Complete Fabrication	10/02/07		Begin fab. post CDR
Operational Readiness Review	10/16/07		@ ILC
Complete Packing & Deployment Trial	11/06/07		@ ILC
Ship Habitat to NSF	11/15/07		Port Hueneme, CA
Deployment at McMurdo	01/08		1-yr deployment





# Inflatable Habitat System Overview

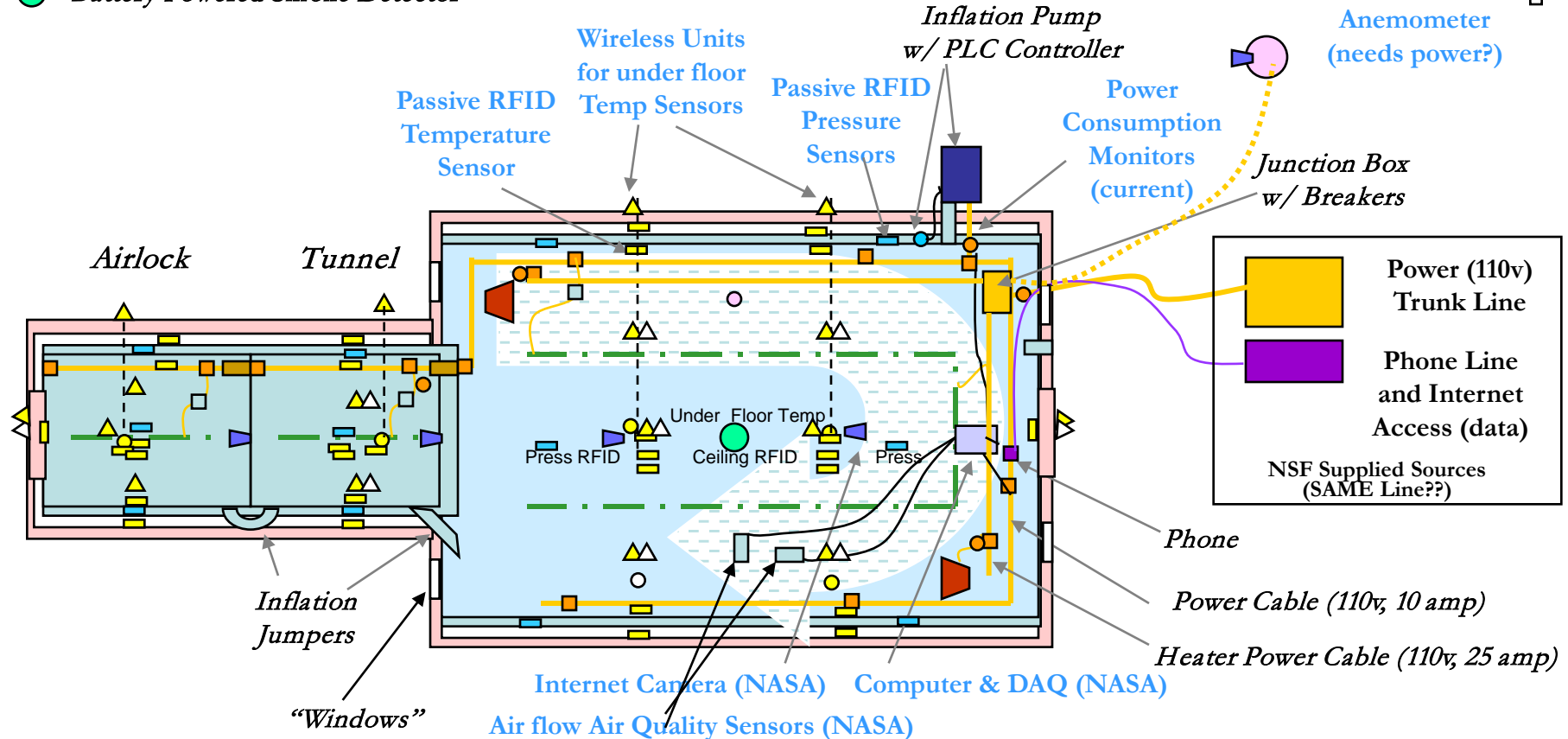




# Antarctic Habitat Instrumentation Layout

- LED Lights
- Light Switches
- Outlets
- Plugs
- Power Cables
- Heaters (Edenpure 500btu quartz convection elect heaters, 110v, 12a, 1500w)
- Battery Powered O<sub>2</sub>/CO<sub>2</sub> Sensor Alarm
- Battery Powered Smoke Detector

- Internet Motion/Activated Camera – link to LED lights?
- Photo-cell Wireless Instrumentation
- Temp RTD Wireless Instrumentation
- Temp RFID sensor (passive preferred)
- Press RFID sensor (passive preferred)
- Current Monitor (wired/wireless)
- Anemometer/Camera







# Habitat Setup at McMurdo Station





# Operations and Data Collection

The screenshot displays a NASA experimental control interface and two webcams. The main interface, titled "NASA EXPERIMENTAL (K-7)", features a central graph showing "Signal 1.6 E - Confidence ST 5" with a green bar chart. Below the graph is a table with 6 columns (0-5) and 10 rows of numerical data. To the left of the graph are several control knobs and buttons, including "Antenna", "Capacitor", "Power", and "Start". To the right are "Antenna" and "Capacitor" labels. Below the table, there are several status messages and a "STOP" button. The bottom left shows a "Task Data" table with columns for ID, Last Update, Mode, and Interval. The bottom right shows a "Task Data" table with columns for ID, Last Update, Mode, and Interval. The right side of the screen shows two webcams. The top webcam, titled "IPP Inflatable Habitat Field Demo Project", shows two people in a room. The bottom webcam, titled "NASA/ISRC HARBOR McMurdo Station, Antarctica", shows a large inflatable habitat in a snowy environment. The task data tables are as follows:

ID	Last Update	Mode	Interval
1021	1/18/2008 8:43:40 AM	Idle	Every 15 seconds
1028	1/18/2008 8:43:41 AM	Idle	Every 15 seconds
1042	1/18/2008 8:43:41 AM	Idle	Every 15 seconds
1019	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1026	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1043	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1027	1/18/2008 8:43:44 AM	Idle	Every 15 seconds
1018	1/18/2008 8:43:29 AM	Idle	Every 15 seconds
1014	1/18/2008 8:43:41 AM	Idle	Every 15 seconds

ID	Last Update	Mode	Interval
1021	1/18/2008 8:43:40 AM	Idle	Every 15 seconds
1028	1/18/2008 8:43:41 AM	Idle	Every 15 seconds
1042	1/18/2008 8:43:41 AM	Idle	Every 15 seconds
1019	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1026	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1043	1/18/2008 8:43:42 AM	Idle	Every 15 seconds
1027	1/18/2008 8:43:44 AM	Idle	Every 15 seconds
1018	1/18/2008 8:43:29 AM	Idle	Every 15 seconds
1014	1/18/2008 8:43:41 AM	Idle	Every 15 seconds





# Results and Lessons Learned

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- ◆ The inflatable portions of the system were packed and deployed approximately 20 times without affecting integrity
- ◆ Sensors integrated into the structure survived packing, shipping, and deployment operated without anomalies for the entire period of deployment
- ◆ The system was erected (unpacked, integrated, and inflated) in 50 minutes by three people wearing cold weather gear and with winds gusting to 32 km/hr
- ◆ The structure adapted well to a slightly undulating surface but the need for compliant structures and attachments was evident
- ◆ The structure was inflated and deflated multiple time in cold conditions (~ -18 deg C to -1.6 deg C) without damage
- ◆ The sensor system worked well throughout the 12 month deployment
  - Occasional computer internet connection resets were required; these were accomplished by on-site personnel
- ◆ Measured thermal and power usage data were correlated and modeled
- ◆ The Innovative Partnership Program worked well for a fast-paced development program involving multiple government agencies and private industry





**Example 2:**

**NASA's Exploration Systems Mission Directorate and OCT  
Innovative Partnerships Office**

# **HABITAT DEMONSTRATION UNIT AND (X-HAB) ACADEMIC INNOVATION CHALLENGE**



# Habitat Demonstration Unit Overview

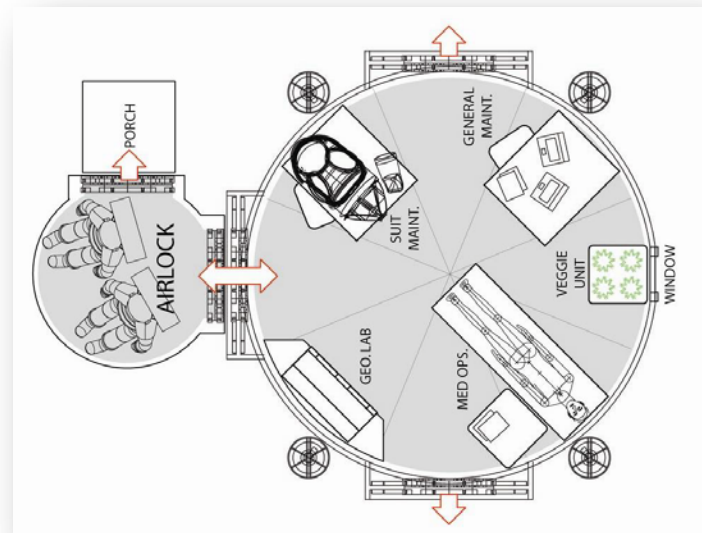
- **The Habitat Demonstration Unit (HDU) was developed as a test bed to:**
  - Obtain human-in-the-loop performance data during field trials of simulated planetary surface exploration
  - Integrate and examine alternative mission architectures
  - Requirement definition/validation
  - Operations definition/validation
- **Recent field test objectives:**
  - To evaluate the Net Habitable Volume (NHV) of the Pressurized Excursion Module (PEM)
  - To assess the effectiveness of the internal architectural design of work stations from a human-system interface perspective
  - To gain knowledge on rover resupply operations using logistics support capabilities of PEM





# HDU Characteristics

- Built as a medium fidelity one-story mockup in a laboratory configuration
- Crews docked rovers with PEM using Active-Active Mating Adapters (AAMA)
- PEM dimensions:
  - Diameter = 2m x 5m
  - Total Height = 3.3m
  - End Dome Height = 0.65m
  - Volume = 56m<sup>3</sup>





# Study Preliminary Results for 2010 Field Tests

## ◆ Results are broken into six groups:

1. General Vehicle Assembly and Checkout
2. Station 1: Medical Operations
3. Station 2: General Maintenance
4. Station 3: Suit Maintenance
5. Station 4: GeoScience
6. Rover Resupply Operations





# Preliminary Conclusions

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- ◆ **Baseline human performance was collected on the PEM vehicle**
- ◆ **Volume Acceptability Scale (VAS) and NASA Task Load Index (TLX) data is still being analyzed for final report**
- ◆ **Overall PEM habitability was considered acceptable for a crew of 4 for 14 to 30-days**
  - No participants actually stayed inside PEM for 14 or 30 days
- ◆ **Overall PEM design/layout and position of work stations was considered acceptable**
- ◆ **Trash management and inventory management for vehicle needs improvement**
- ◆ **Stowage was issue with all work stations**
- ◆ **Medical Ops Station**
  - Provided 360° access around patient with adequate table surface
  - Privacy, contamination, and stowage are areas needing further improvement
- ◆ **General Maintenance Station**
  - Scored extremely well with horizontal work surface and fold-out concept; but, mechanical design improvement is needed for less cumbersome operation
  - Adjustable table would add more flexibility to table design
  - Some interference with Suit Maintenance Station





# Preliminary Conclusions

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## ◆ Suit Maintenance Station

- Overall layout was considered acceptable; however, need adjustable table, small containers for parts and better laptop arm location
- Functionality of PLSS mounting rig needs improvement
  - Subjects noted rig felt unstable due to cantilevered nature
  - When rig was horizontal left locking handle could not be actuated
  - Attaching PLSS or SPTM was difficult due to clamp design

## ◆ Geo Science Station

- Station located in good area for 4 crew working with plenty of volume to operate
- Adjustable stool or platform is needed to accommodate shorter subjects for access to glove box and touch screens
- Overall design/layout was considered borderline
  - Subjects had difficulty reaching data recording devices
  - Gloves were hard to take off
  - Subjects had difficulty reaching all parts of the glove box while gloved
  - Difficulty for shorter subjects to look up and see overhead monitors due to site angle





# Preliminary Conclusions

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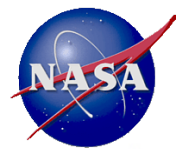
- **Resupply Operations**

- Resupply in PEM was considered acceptable

- PEM volume was tight with crew of 4 but not impossible to get work done
    - PEM hatch size for transfer was good and subjects reported did not want hatch any smaller
    - With soft locker gear spread around subjects found it difficult to organize gear
    - Subjects was frustrated by lack of resupply procedures

- Resupply from Rover to PEM was considered acceptable

- Overall volume supports ability to transfer items between vehicles
    - Utilizing PEM was convenient and allowed for proper packaging prior to crew swap out
    - PEM easy to access through AAMA tunnel
    - Better understanding of logistical processing



# X-Hab Academic Innovation Challenge

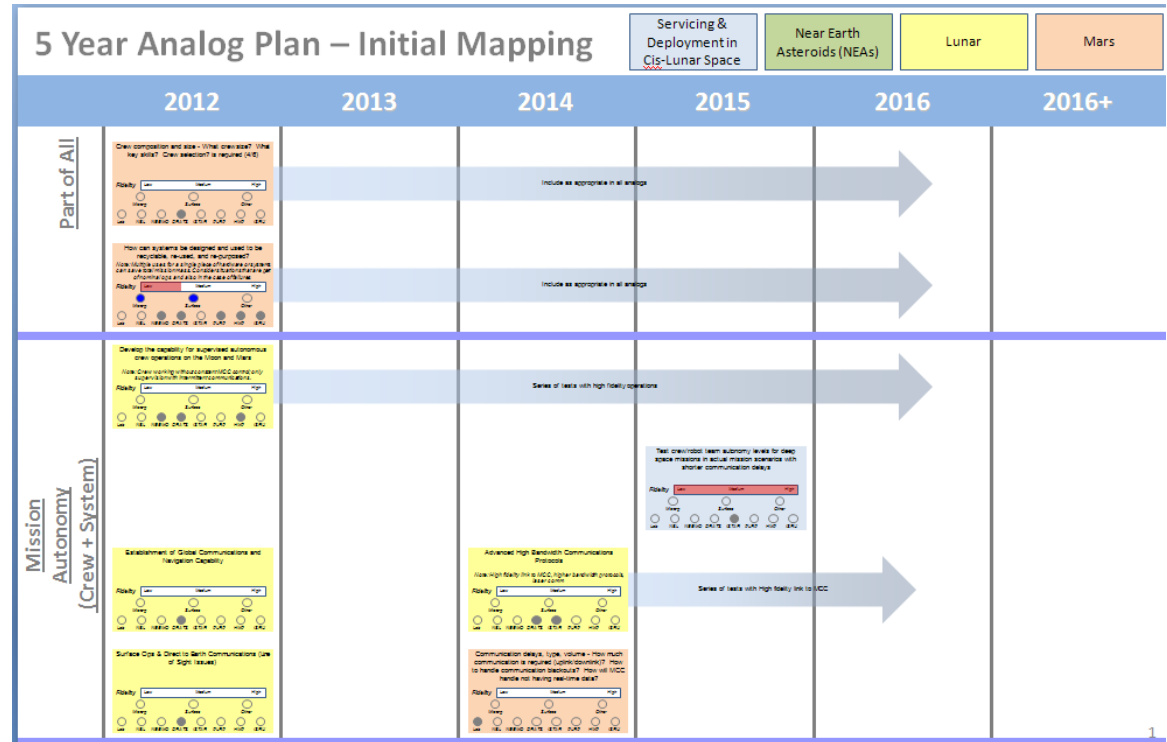
- ◆ **The eXploration Habitat (X-Hab) Academic Innovation Challenge is a university-level competition designed to engage and retain students in Science, Technology, Engineering and Math (STEM) disciplines.**
  - NASA will directly benefit from the competition by sponsoring the development of innovative habitat inflatable loft concepts from universities which may result in innovative ideas and solutions that could be applied to exploration habitats.
  
- ◆ **On July 1, 2011, the University of Wisconsin-Madison was announced as the winner of the 2011 X-Hab Academic Innovation Challenge.**
  - ◆ The team integrated their design with the HDU-Lab during the September 2011 Desert Research and Technology Studies (Desert RATS) analog field test.



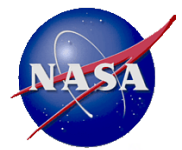


# Overall Conclusions

- ◆ Begin to align analogs with questions and assumptions arising from possible HSF destinations



- ◆ Approaches such as the Innovative Partnership Program provide a means for industry, academia, and other government agencies to help advance NASA's exploration of the Solar System while gaining insight into NASA's advanced systems and operations



# Backup

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# Inflatable Habitat System Components

